A GaAs-AlGaAs BASED THYRISTOR

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Abstract: A study of bipolar junction thyristors based on GaAs and AlGaAs materials for pulsed power switching applications is reported. Novel aspects of the device and fabrication processes required by the design are discussed, and preliminary results of the GaAs homojunction thyristors are presented and analyzed.

Introduction

Recently various groups [1] have shown that solid-state switches fabricated with GaAs and related III-V heterostructures can be made to exhibit subnanosecond current rise-times under pulse power conditions, and thus should be considered for high power, fast switching purposes. Both homojunction and heterojunction bipolar thyristors based on GaAs and AlGaAs materials have been investigated. Preliminary p-n-p-n structures of planar geometry were able to hold over 1 kV for certain samples, and the current rise-times were measured to be less than 200 psec for 6-A peak currents, which are approximately an order of magnitude faster than those of the best Si thyristors.

GaAs, compared to Si, has inherent advantages that are desirable for pulsed power applications. Sze and Gibbons [2] have shown that the reverse-biased avalanche breakdown voltage of ideal GaAs p-n junctions, are larger than that of Si junctions. Also, GaAs electron mobility is 5-6 times larger than Si electron mobility; therefore, any device that depends on the transit time of the electrons definitely favors GaAs. GaAs with a larger bandgap is less sensitivity to temperature and radiation. In addition, the direct bandgap of GaAs provides a fast, radiative band-to-band recombination, while the indirect band gap of Si gives a slower, non-radiative recombination which involves generation of phonons and heating of the lattice. The radiative nature of the recombination in GaAs thyristors adds a new aspect to the device operation - internal optoelectronic triggering. The p-n LED at the gate generates photons which are uniformly distributed throughout the device to turn-on the whole device homogeneously. This is believed to be the mechanism that provides the fast current switching.

Device Structure and Fabrication

A new device structure, currently under investigation at USC, is shown in Fig. 1. This device has a thick middle base layer, comprised of semi-insulating GaAs, either LEC (liquid encapsulated Czochralski) grown or Cr-doped Bridgman grown. This bulk base layer enhances the power handling capability of the device. The punch-through barrier layers and emitter layers, which are 1-5 μm thick and relatively highly doped, are epitaxially grown on both sides of the wafer using an MOCVD (metal organic chemical vapor depostition) technique. Thus, the base structure is essentially a p-i-n structure, unlike the p-n structure of a conventional thyristor. Photolithography and chemical etching commonly used for GaAs laser fabrication were also used for the GaAs thyristor fabrication.

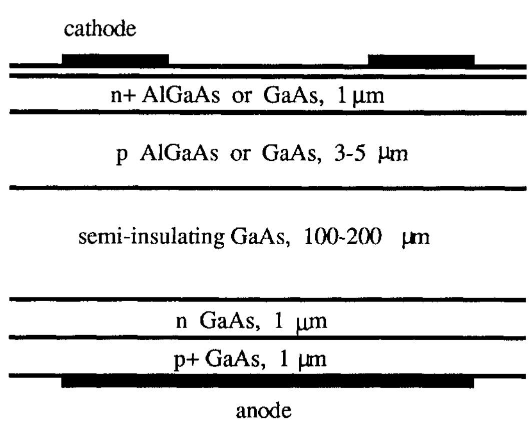

Fig. 1. GaAs thyristor structure being studied at USC. The AlGaAs layers provide optical windows for the GaAs laser triggering.

In one set of devices, all layers were grown with GaAs material. In another set of devices, the p-barrier and n+-emitter layers were grown with AlGaAs material. These layers function as optical windows and thus allow an efficient coupling of the triggering light to the critical base region during the turn-on process.

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Experiment and Results

The fabricated devices were cleaved to dimensions of few millimeters on the sides. The devices were then placed on a copper heat sink. An AlGaAs laser diode was used as an optical triggering source for the thyristor. The laser output window was placed approximately 5 mm from the cathode surface of the device. The diode laser was operated in a single-shot mode with the laser pulse energy of 1-2 μJ, and the pulse width of ~100 nsec. The peak lasing wavelength was 848 nm.

Preliminary results of the GaAs homojunction device is presented here. The metallized samples were able to hold DC voltages between 160 and 250 volts; beyond the breakover voltage, the devices would experience an irreversible self-breakdown. When the edges of these devices were cleaved, the remaining portion of the devices again were able to hold similar voltages. This indicates that a permanent breakdown has occured at the edges of the devices.

In an attempt to reduce the edge breakdown effect, some samples were not metallized, and point contacts were used. In this setup, the DC holding voltages of the thyristors were greater than 540 volts. After a self-breakdown, the devices were able to hold similar voltages repetitively.

These point-contacted samples were tested in a pulsed mode using the circuitry shown in Fig. 2. We were able to trigger the point-contacted devices with the laser diode operating with pulse energies as low as 0.6 μJ. The DC holding voltage was varied from 300 to 540 volts. With 1-Ω load resistor, the peak current was measured to be as high as ~70 A . This corresponds to a current density of approximately 2500 A/cm^2. The rise time was less than 100 nsec and was limited by the external circuitry. (Also, the resolution of the digital oscilloscope was 50 nsec.) An optimum circuit configuration was not used in these preliminary experiments.

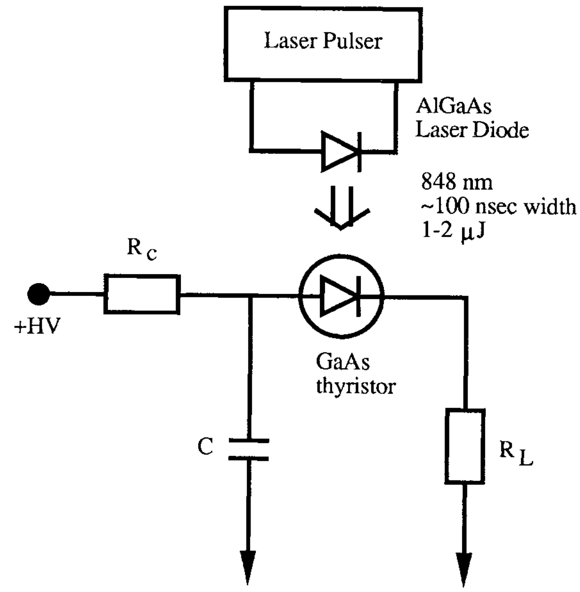

Fig. 2. Schematic diagram of the circuitry used to test GaAs opto-thyristors in pulsed mode.

Analysis and Conclusions

We now analyze the performance of the devices. The breakover voltage of the device can be calculated by considering the avalanche effect in the bulk base layer and the punch-through effect in the barrier layers. Using the impact ionization coefficients from Bulman *et al.* [3] and considering the transistor effect, the device breakover voltage is calculated to be ~1300 volts for 100-μm bulk base layer. The forward voltage drop is computed by considering the device as a p-i-n diode [4]; the expected forward voltage drop in the ON state then is ~6 V. The current rise time is related to the carrier transit time across the bulk base layer; the transit time is in the order of few nanoseconds.

The measured breakover voltage of the GaAs thyristor is smaller than the calculated value. We attribute this early breakdown of the thyristors to one of the two possible effects: edge breakdown and deep-level effects. The deep-level effects are due to a high density of EL2 or Cr deep levels present in semi-insulating GaAs materials. These deep levels can function as carrier traps, and the trapped carriers can be impact ionized at an electric field that is smaller than that for the band-to-band impact ionization [5]. These deep levels can also behave as recombination centers for the carriers transporting across the base layer, thus reduce the lifetime of the carriers. This reduction in lifetime would increase the forward voltage drop of the thyristors.

We conclude from the preliminary experiments that the edge breakdown is a major problem issue that needs to be addressed. Possible solutions that will be considered for the future work are as follows: isolate the device from the edge by etching a moat around the device, and bevel the device edges by angle-polishing to reduce the electric field at the edges.

Concurrently, an epitaxial growth of highly pure, thick layers for the thyristor base region is being pursued. LPE (liquid phase epitaxy) seems to be the best technique for this purpose. The LPE technique has the capability to satisfy the thickness requirement, and has the impurity gettering property that are desirable for purity requirement. Also, the LPE technique allows low temperature growth which is quite important in reducing the contamination from the solvent container.

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